Evaluation of the AoR Delineation Modeling Approach in Carbon TerraVault's Monterey Formation 26R Class VI Permit Application

This area of review (AoR) delineation modeling evaluation report for the proposed Carbon TerraVault (CTV) Elk Hills 26R Class VI geologic sequestration project summarizes EPA's evaluation of the modeling performed by CTV as described in the Area of Review and Corrective Action Plan (AoR CA), which is Attachment B to CTV's November 5, 2021 permit application, and associated files submitted to the AoR and Corrective Action Module of the GSDT. This review also addresses modeling-relevant site characterization information in the permit application narrative and in the Post-Injection Site Care (PISC) and Site Closure Plan (Attachment E). Clarifying questions for CTV and requests for supplemental information are provided within the text below

It is assumed that planned pre-operational testing will confirm the site characterization information. Please note that modifications to the model parameters may be needed if this testing yields results that are significantly different than the model inputs described in the initial permit application.

Evaluation of the Geomodel

Representation of Site Geologic Features

To delineate the Class VI AoR, the geological layering, formation thicknesses, and petrophysical properties of the project site (as described in the permit application narrative and evaluated in the geologic site characterization report) need to be integrated into a geomodel and then into a numerical model domain that is consistent with site-specific geologic and operational information to generate predictions of plume and pressure front movement.

The four CTV 26R project injection wells will inject CO_2 into the Monterey Formation's 26R Sands in the Elk Hills Oil Field (EHOF) within the San Joaquin Valley of California. The injection zone is within the 31S anticline, a northwest-southeast trending anticlinal structure located in the EHOF. The injection zone consists of stacked turbidite sands within the Monterey Formation and is interbedded with siliceous shales and clays. The Monterey Formation 26R Sands pinch out on top of the 31S anticline and along strike (as seen in Figure 1 of the AoR CA). The confining unit above the Monterey Formation is the Reef Ridge Shale, which is a regionally extensive deep marine, clay-rich interval with an average gross thickness of about 1,000 ft and a low matrix permeability. It has acted as the primary sealing unit for all Monterey Formation oil and gas accumulations in the EHOF based on historical production well performance.

CTV used geologic and hydrologic data derived from multiple sources for their geomodel and numerical modeling approach. These sources include well data, open-hole well logs and cores (the locations are shown in Figure 2 of the AoR CA), and reservoir performance information (including production and injection rates and volumes, reservoir, and wellbore pressures). The representation of site geologic features, including lithologic properties, and geomechanical behavior appears to be appropriate and is reflected in the applicant's static geomodel and computational model. However, some information was omitted, including the injection zone fracture pressure derivation and stratigraphic discretization (requests for this information are provided in sections below). Additionally, Figure 1 of the AoR CA demonstrates normal faulting above the Reef Ridge Shale over the 31S anticline. Figure 9 of the permit application narrative demonstrates reverse faulting below the Monterey Formation, penetrating the lowermost portion of the lower Monterey Formation. However, no observation-based examples (e.g., seismic reflections/terminations) or geologic reasoning supporting the absence of faults in the Monterey Formation 26R Sands and Reef Ridge Shale confining zone is provided.

Questions/Requests for the Applicant:

- *Please show the location of CTV's proposed Class VI injection wells in Figure 2 of the AoR CA. Additionally, provide a legend defining the various well icons in the figure.*
- *Please provide observation-based examples (e.g., seismic reflections/terminations) and geologic reasoning that supports the absence of faults in the Monterey Formation 26R Sands and Reef Ridge Shale confining zone.*
- *Please provide a higher resolution version of Figure 1 of the AoR CA with clearer labels and text.*

Representation of Hydrogeologic Properties and Lithology

Porosity, permeability, and rock types

Figure 2 of the AoR CA shows well penetrations for which there is data from open hole triple-combo logs (resistivity, neutron porosity, bulk density) and core data. Model parameters including porosity, facies, and clay volume were derived from the open hole logs and upscaled into the geological model using Gaussian random function simulation (kriging). Mercury injection capillary pressure (MICP) permeability data from core analysis was used to constrain the porosity-permeability function shown in Figure 4 of the AoR CA. Permeability is a function of porosity and clay volume. Figure 6 shows that the highest porosity and permeability values exist near the crest of the anticline, with decreased values on the limbs of the anticline. Additional discussion of porosity and permeability is included in pg. 15-18 of the permit application narrative.

Questions/Requests for the Applicant:

- *Please edit Figure 6 to include labels of the geologic formations. Additionally, please add additional geologic layers to demonstrate the geologic structure relative to the porosity and permeability distribution.*
- *The correlation coefficient in Figure 4 is illegible. Additionally, it is unclear what value (porosity or clay volume) is represented on the X-axis. Please render the correlation coefficient so that it is legible and clarify what value is used on the X-axis.*
- *Please label the X and Y axes on Figure 5.*
- *Please edit Figure 6 to include labels of the geologic formations. Additionally, please add additional geologic layers to demonstrate the geologic structure relative to the porosity and permeability distribution.*

Geomechanical properties

The geomechanical properties of the Monterey Formation 26R reservoir and Reef Ridge Shale confining zone were derived from compressional sonic data from 11 wells and MICP measurements from Well 355X-30R. Borehole breakout data from the EHOF and literature reviews also aided in characterizing fracture behavior. A corresponding geomechanical model was generated to assess the failure pressures for the reservoir and confining zone. CTV included relevant discussion concerning geomechanical modeling and properties in the permit application narrative; please also see the geologic site characterization report for discussion.

A summary of fracture pressure data for the Monterey Formation 26R reservoir is provided in Table 6 of the AoR CA, which is replicated below. The applicant states that injection pressure will be below 90% of the Monterey Formation 26R fracture gradient at the base of the Reef Ridge Shale in the AoR (6,826.6 ft TVD as seen in Table 7 of the AoR CA, replicated below). The planned maximum subsurface wellbore injection pressure for the project is 4,900 psi.

The elevation of the top of the perforated interval in Table 7 is inconsistent with the depths on a well diagram for Well 373-35R, which was provided in a confidential file that contains schematics for the wells in the AoR. Accounting for the elevation of the well relative to mean sea level (1,329 ft), the top of the perforated interval would equate to 6,813 ft TVD. A similar discrepancy exists in Table 5, which shows the top and bottom of the perforated intervals, which would equate to 6,813 to 7,618 TVD.

Table 6 of the AoR CA: Summary of the fracture pressure data for the Monterey Formation 26R reservoir at the 373-35R well.

Interval	Breakdown Fracture Gradient PSI/foot	Fracture Pressure (PSI) at base of Reef Ridge Shale (6826.6 feet TVD)
Monterey Formation 26R	1.03	7,031

Table 7 of the AoR CA: Injection pressure details

Injection Pressure Details	**Injection Well 1 373-35R**
Depth corresponding to maximum injection pressure (ft TVD)	6,826.6
Breakdown Fracture gradient (psi/ft)	1.03
Calculated maximum injection pressure at the top of the perforated interval (psi)	7,031
Maximum injection pressure (90% of fracture pressure) (psi)	6,327.9
Elevation at the top of the perforated interval (ft MSL)	-5,484
Planned maximum injection pressure/ gradient (top of perforations)	4,900 / 0.71

Questions/Requests for the Applicant:

- *What data from which tests were used to establish the fracture pressure listed in Table 6 of the AoR CA? Additionally, please discuss how testing during the pre-operational phase will further establish the fracture pressure of the injection zone. If Step Rate Testing (SRT) will be used to determine fracture pressure, please describe the testing procedure, including the fluid to be used and how it is representative of the CO_2 injectate.*
- *The elevations at the top of the perforated intervals (ft MSL) for Injection Well 373-35R in Tables 5 and 7 of the AoR CA do not correspond with the perforated interval depths for this injection*

well in the 373-35R well diagram. Please resolve this discrepancy and revise Tables 5 and 7, and/or the well diagram accordingly.

- *The planned injection pressure/gradient for Well 373-35R are listed as 4,900 psi / 0.71 psi/ft in the last row of Table 7 of the AoR CA. Please clarify if these values are indeed a maximum, or if they are a planned injection pressure/gradient. If they are not a maximum, please edit Table 7 to exclude the word "maximum" in "Planned maximum injection pressure/ gradient (top of perforations)."*

Objectives for Pre-Operational Testing:

- *Confirm the fracture pressure of the injection and confining zones, i.e., by performing an SRT in each zone.*

Geomodel – 3D model grid resolution and discretization

The Petrel static geomodel was used as the framework for the GEM numerical model. The geo-cellular grid is uniformly spaced throughout a 3.7 square mile area with a cell size of 190 ft x 150 ft. The model grid is oriented at 18 degrees, which corresponds to both the structural trend of the anticline and the depositional environment. The model boundaries were selected based on plume extent and the edges of the Monterey Formation 26R reservoir. CTV submitted an example image of the geo-cellular grid to the GSDT in a file titled 26R—Grid--Image.jpg. The image demonstrates uniform geo-cellular spacing, a northwest-southeast orientation, and a consistent structural trend, deepening towards the southwest.

The reservoir was separated into twelve zones and 27 layers and an average grid cell height of 117 ft (Figure 3 in AoR CA). Grid resolution was idealized based on simulation run-time and retaining reservoir heterogeneity. The grid files are claimed as confidential business information (CBI) and were not submitted to the GSDT (but were provided to EPA by a separate means).

Questions/Requests for the Applicant:

- *Please discuss how the lateral dimensions and vertical thickness of the Petrel static geomodel were chosen, and the significance of such values (i.e., 10 miles x 10 miles laterally, 3,000 ft thick).*
- *Please discuss how the total grid dimensions laterally and vertically (i.e., 190 x 150 cells laterally, 27 layers vertically) were chosen.*
- *Please discuss the vertical layers (stratigraphy) that were included in the model and why cell size height may vary between vertical layers.*
- *Please discuss why the Monterey Formation 26R Sands were modeled as twelve separate zones, when according to the geologic narrative, it comprises a single injection zone.*
- *Please show the extent of the AoR and the location of CTV's proposed Class VI injection wells on all maps (e.g., Figure 2) of the AoR CA.*
- *Please label the vertical layers shown in Figure 3 of the AoR CA, especially the injection and confining layers. Additionally, please show the location of CTV's proposed Class VI injection wells on the inset base map and cross-sectional views.*

Fault stability

Faults were not incorporated into the geomodel due to the lack of evidence of faults that transect the Monterey or Reef Ridge Shale Formations in the AoR. However, given the syndepositional structural behavior during the deposition of the Monterey Formation 26R Sands as noted in the permit application narrative, discussion and observation-based examples supporting the exclusion of faults in the geomodel are needed; these are requested under “Representation of Site Geologic Features,” above. CTV included relevant discussion concerning fault stability in the permit application narrative; please also see the “Representation of Site Geologic Features” section above and the geologic site characterization evaluation report for discussion.

Evaluation of the Computational Model Design

The applicant’s discussion of computational model design includes but is not limited to: subsurface phase properties and behavior, CO_2 plume size and extent, boundary and initial conditions, timeframe and time steps, operational information, model calibration and sensitivity analysis, and injection zone storage capacity. EPA considers the applicant’s discussion of the computational model design and associated components to be appropriate and relatively complete, however there are several outstanding questions that need to be addressed in order to consider the material in this section sufficient, as described in the sub-headings, below.

Routines for Relevant Subsurface Processes

The applicant used Computer Modeling Group’s (CMG) Equation of State GEM Compositional Simulator to perform the AoR delineation. GEM is capable of modeling three components (gas, oil and aqueous), multi-phase fluids and predict phase equilibrium compositions, densities, and viscosities of each phase. The applicant states that CMG incorporates all relevant physics-based approaches to relate relative permeability to interfacial tension (IFT), velocity, composition, and hysteresis. CTV also referenced multiple peer reviewed papers in which CMG’s GEM software has been applied to CO_2 sequestration. The Peng-Robinson Equation of State is used for the computational modeling of the CO_2 plume, and establishes the interaction or solubility of CO_2 and residual oil in the reservoir. The solubility of CO_2 in water is modeled by Henry’s Law as a function of pressure, temperature, and salinity.

The permit application states that predicting the evolution of the CO_2 plume involved: integrating reservoir characteristics and wells found in the static Petrel 3D geomodel; inputting injection pressure and rates in the GEM computational modeler; and assessing CO_2 plume movement throughout the injection and post-injection intervals until the plume reached pressure and compositional equilibrium.

Spatial Extent

The AoR was determined by the largest extent of the CO_2 plume from computational modeling results. In the AoR scenario, CO_2 was injected into the reservoir until the reservoir reached the initial discovery pressure of 3,250 psi. The application asserts that this process ensures that there is no increased pressure front beyond the original reservoir limits.

Questions/Requests for the Applicant:

- *Please explain the specific method used to define the AoR boundaries (i.e., percent CO_2 saturation cutoff or a qualitative method).*

Boundary Conditions

No-flow boundary conditions were established for the Monterey Formation 26R reservoir in the computational modeling. The overlying confining unit, the Reef Ridge Shale, is continuous throughout the area, has a low permeability (less than 0.01 mD), and has confined oil and gas operations (that include injection) since discovery of the field. Well performance data from the Monterey Formation 26R oil and gas reservoir, shown in Figure 8 of the AoR CA, is asserted to demonstrate that there is no connection to an aquifer. Historical production shows minimal water production, supporting the lack of aquifer connectivity. Gas injection and subsequent gas blow-down supports lateral and vertical confinement by demonstrating that gas did not migrate out of the reservoir. Finally, reservoir pressure is approximately 150-300 psi and has not shown an increase due to aquifer influx.

Questions/Requests for the Applicant:

- *Please provide historical pressure data for the Monterey Formation 26R reservoir demonstrating pressure isolation.*

Time Steps and Model Timeframe

The computational modeling results for CO_2 plume development at 4 different time-steps are shown in plan view (Figure 9) and cross-sectional view (Figure 10) of the AoR CA. The time-steps are Year 5 of injection, Year 10 of injection, Year 25 post injection, and year 100 post injection. The model simulation appears to have occurred over a 126-year timeframe (i.e., the 26-year injection phase plus 100 years post-injection), but this is not clear. For all layers within the model and at all time-steps, the CO_2 plume remains within the 3.7 square mile AoR. Within the first 15 years of injection, the CO_2 plume is largely defined. After 15 years, the CO_2 concentration within the plume increases until the 25 years post injection time-step. The CO_2 concentration is largely unchanged between the 25-year and 100-year post injection time-steps.

The application describes that CO_2 injected into the Monterey Formation 26R reservoir will be soluble in both water and oil. Due to the low remaining oil and water saturations in the reservoir, the injected CO_2 that will be dissolved in oil and water is predicted to be 20% and 8%, respectively. The remaining 72% of the injectate will be stored in the reservoir as supercritical CO_2. Figure 11 of the AoR CA demonstrates the cumulative storage for each of these mechanisms (oil, water, supercritical CO_2).

Questions/Requests for the Applicant:

- *Please add a discussion regarding the time at which the CO_2 plume and pressure front are expected to reach their maximum vertical and lateral extent. Additionally, please discuss the boundaries at which this extent is defined.*
- *Please add the injection wells to Figures 9 and 10, and label the vertical layers on Figure 10.*
- *Please clarify the total simulation period (i.e., whether it is 100 years total or the injection period plus 100 years).*

Initial Conditions and Operational Information

Initial model conditions at the beginning of CO_2 injection have been established and verified over time during oil and gas production from the Monterey Formation 26R reservoir. Initial conditions for the model are given in Table 4 and operational information is presented in Table 5, which are replicated below.

Table 4. Initial conditions.

Parameter	Value or Range	Units	Corresponding Elevation (ft MSL)	Data Source
Temperature	210	Fahrenheit	5,630	Fluid Analysis
Formation pressure	150-300	Pounds per square inch	5,630	Pressure Test
Fluid density	61	Pounds per cubic foot	5,630	Water analysis
Salinity	25,000	Parts per million		Water analysis

Table 5. Operating details.

Operating Information	Injection Well 1 373-35R
Location (global coordinates) X Y	 35°16'34.5276"N 119°28'24.1836"W
Model coordinates (ft) X Y	 6121906 2290081
No. of perforated intervals	13
Perforated interval (ft MSL) Z top Z bottom	 -5,484 -6,289
Wellbore diameter (in.)	7
Planned injection period Start End	 2044 2070
Injection duration (years)	26
Injection rate (t/day)*	993

*If planned injection rates change year to year, add rows to reflect this difference, and include an average injection rate per year (or interval if applicable).

Questions/Requests for the Applicant:

- *Please add the reference elevation to Table 4.*
- *The beginning and end dates of injection in Table 5 (i.e., years 2044 and 2070) and the beginning date on Figure 11 (i.e., 2044) do not correspond to the proposed beginning of injection (year 2025) stated in the permit application narrative. Please clarify this difference and update Table 5, Figure 11, and/or the permit application narrative as needed.*

Relative permeability and capillary pressure curves

Gas, oil, and water are all present in the Monterey Formation 26R Reservoir. Contact depths have been derived from open-hole logs, production analysis, and history matching, and saturations have been assumed; however, the AoR CA does not provide the basis for the assumptions. With all three phases present in the reservoir, three-phase relative permeability relationships were used in the computational model to characterize the flow of each phase. To determine three-phase relative permeability, two sets of two-phase relative permeability data are needed: water-oil and gas-oil relative permeability. The two-phase relative permeability relationships allow the determination of Krw, Krow, Krg, and Krog as a function of water or liquid saturation. Core flood and MICP data were used to determine the two-phase relative permeability relationships. Figure 7 of the AoR CA presents the relative permeability curves used in the computational modeling.

Questions/Requests for the Applicant:

- *Please explain the method used for determining the saturation values for gas, oil, and water.*
- *Please include definitions for Krw, Krow, Krg, and Krog in Attachment B.*
- *Please explain how the relative permeability relationships vary with rock type, and how these permeability relationships were derived.*
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Potential Pathways for Fluid Movement

Faults

CTV included relevant discussion concerning fault stability in the permit application narrative. Please also see the "Representation of Site Geologic Features" and "Fault Stability" sections above, and the geologic site characterization report for discussion.

Wells in the AoR

The AoR CA states that 204 wells in the AoR penetrate the Reef Ridge Shale confining zone and Monterey Formation 26R reservoir. These wells are tabulated in Table 8 of the AoR CA, and presented in a map in Figure 13. Appendix 1 to the AoR CA provides information about the 204 wells in the AoR, including well name, API number, type, status, spud date, and locational information (e.g., latitude/longitude and surface coordinates). However, no depth or completion formation is provided, so it is unclear how many of the wells penetrate the entire Reef Ridge Shale, and if they are accounted for in the computational model. Additional discussion regarding wells in the AoR is presented under "Corrective Action on Wells in the AoR," below.

Calculation of critical pressure

CTV submitted critical pressure information to the GSDT in a file titled "Critical—Pressure—Calculation.PDF." However, they did not conduct a critical pressure calculation due to the absence of a USDW within the modeled AoR. (The applicant asserts that the Upper Tulare Formation is an unsaturated zone, and the Lower Tulare Formation is an exempt aquifer.) The permit application asserts that the final pressure of the Monterey Formation 26R reservoir will be at or below the initial reservoir pressure of 3,250 psi, ensuring that post-injection conditions replicate those of initial conditions to the extent possible. Therefore, the AoR is based on the extent of the modeled CO_2 plume.

Questions/Requests for the Applicant:

- *Do any of the 204 wells in the AoR penetrate the entire Reef Ridge Shale? If so, please explain how they are accounted for in the geomodel.*

Objectives for Pre-Operational Testing:

- *If, based on additional information, the Upper Tulare is determined to be a USDW within the AoR of the 26R project, please provide documentation of the critical pressure calculation.*

Representation of Fluid Properties

Because a baseline injectate analysis has not yet been performed, limited information about the CO_2 stream is available and relevant CO_2 injectate fluid properties for the numerical modeling are not included in the AoR CA. The applicant did not submit an operating plan for the proposed wells with this information. Additionally, the applicant did not include reactive transport modeling as part of the overall modeling effort. It appears this might be due to the dominant quartz/feldspar mineralogic framework of the reservoir, as noted in the permit application narrative. However, an explanation regarding the lack of reactive transport modeling is needed.

Questions/Requests for the Applicant:

- *Please update the AoR CA to include fluid properties for the CO_2 injectate used in the computational modeling, including but not limited to its viscosity, density, salinity, and fluid compressibility.*
- *Please explain why reactive transport modeling was not performed or included in the computational model.*

Objectives for Pre-Operational Testing:

- *Confirm that the properties of the CO_2 stream based on pre-operational injectate sampling are consistent with the model inputs.*

Model Calibration and Sensitivity Analyses

CTV used information derived from extensive past injection operations to inform a sensitivity analysis. The CO_2 plume model results were compared with the area of the reservoir that has been depleted by oil and gas operations.

As a computational model sensitivity, CTV states (on pg. 13) that it ran the simulation model for different initial reservoir pressure and saturation cases to determine the sensitivity of the storage volume and plume extent to these variables. However, the sensitivity cases and their associated data were not provided.

To verify the modeled predictions, monitoring wells will be used for CO_2 plume and pressure front tracking, via fluid sampling and pressure and temperature monitoring. Reservoir pressures based on monitoring data and injection volumes will be integrated in order to complete material balance equations to verify pore volumes and AoR edges. Additionally, the CO_2 plume and water contact will be calculated from the monitoring well pressure, CO_2 saturation, and column height. If the reservoir pressure associated with injected volumes does not follow the anticipated trend from computational modeling, CTV states that it will reevaluate the AoR.

Questions/Requests for the Applicant:

- *Please provide a narrative discussion and associated data (i.e., inputs, maps, pressures, etc.) for the sensitivity cases that were performed as part of the model sensitivity analysis for storage volume and plume extent described on pg. 13; please also provide the results.*
- *Was a sensitivity analysis conducted on grid geometry and petrophysical properties (permeability, porosity, etc.)?*
  - *If so, please discuss the sensitivity analysis and its results.*
  - *If not, please perform a sensitivity analysis..*

Injection Zone Storage Capacity

As stated in the permit application narrative, the storage capacity of the injection zone based on computational modeling results is a maximum of 38 million tonnes of CO_2. Table 5 of the AoR CA lists a daily injection rate of 993 tonnes per day, equating to 362,445 tonnes annually per well, or 1.45 million tonnes annually for all four wells. Over an operating period of 26 years, this sums to a total injectate volume of 37.7 million tonnes of CO_2. This is within the maximum injection zone storage capacity of 38 million tonnes, assuming that all of the wells will inject at similar rates and will be operated continuously/365 days per year. The injection zone does have the potential to store an increased volume of CO_2 at higher pressures while the CO_2 remains within the defined AoR.

Questions/Requests for the Applicant:

- *The modeled injection zone storage capacity is not explicitly stated in the AoR CA. Please confirm if the volume of 38 million tonnes cited in the narrative is correct. If it is not correct, please provide the correct volume.*
- *Please confirm that each well will inject at similar rates to Well 373-35R, as listed on Table 5. If not, please clarify the total volume to be injected by all four wells.*

Presentation of Model Results

Map and cross-sectional views of the simulated plume and pressure front were provided in the AoR CA. The maps show the position of the plume and pressure front after 5 years and 10 years of injection, and 25 years and 100 years post-injection. Figures 9 and 10 show the applicant's proposed AoR as delineated by the simulated CO_2 plume.

The differences in the predicted position of the plume and pressure front between the injection and post-injection time-steps were significant, suggesting that the plume continues to develop after 10 years of injection but before 25 years post injection; the position of the plume and pressure front in the latter part of the injection phase (i.e., years 11-26 of injection) is not presented. CTV should provide plan and cross-sectional views of the plume at the time step for which the plume is expected to no longer be migrating. A discussion should accompany the added plan and cross-sectional figures to address plume migration and eventual plume stability. Updated modeling will be necessary when pre-operational site data becomes available.

Questions/Requests for the Applicant:

- *Please update Figures 9 and 10 of the AoR CA with additional time steps including, at a minimum:*
  - *time steps from the latter half of the injection phase (including year 26);*
  - *the time step that represents the maximum extent of the CO_2 plume and pressure front;*
  - *the time step that represents the point at which the CO_2 plume reaches stability/absence of continued migration; and*
  - *several time steps during the early post-injection phase (e.g., 1, 3, 7, 10, and 15 years after cessation of injection).*
- *Please provide a narrative discussion to describe the plume evolution before, during, and after the point at which the CO_2 plume reaches stability/absence of continued migration.*

Corrective Action on Wells in the AoR

The AoR CA says that documentation of the 204 wells in the AoR that penetrate the Reef Ridge Shale confining zone is provided in Appendix 1, which is an Excel file (AoR—Well--List) containing the name, surface location, and status of 204 wells, but it does not contain information on drill date, type, and depth to Reef Ridge Shale confining zone that is required at 40 CFR 146.84 (c)(2). This information is summarized on Table 8 of the AoR CA, which indicates that 36 of the 204 wells are plugged (which corresponds to information in the Excel file). Figure 13 of the AoR CA shows a map view of the 204 wells that penetrate the Reef Ridge Shale confining layer and Monterey 26R Formation. The applicant states that these wells were reviewed for corrective action.

The applicant says that the determination that all 204 wells in the AoR penetrate the confining zone was made by reviewing open hole logs and deviation surveys of each well. The AoR CA plan says that well condition, mechanical integrity, and data completeness is routinely reviewed with CalGEM. The wells located within the AoR were last reviewed in Q4 of 2021.

Table 9 of the AoR CA indicates that 168 wells will be abandoned prior to injection: one will be repurposed as a CO_2 injector, three wells will be repurposed as monitoring wells; and the remaining 164 wells require standard plugging procedures as part of asset retirement obligations (these procedures are not described, however). It is unclear based on the text or table which wells these are and if they are the only wells that penetrate entirely through the Reef Ridge Shale, however.

The AoR CA also states (pg. 17) that all wellbores within the AoR will, if necessary, be pressure tested, abandoned, re- abandoned, monitored, or have a technical demonstration showing adequate zonal confinement prior to the commencement of CO_2 injection or based on an agreed upon phased schedule post CO_2 injection if conditions allow. The plan also asserts that there is no USDW present in the AoR; this statement needs to be confirmed (see EPA's geologic evaluation).

Questions/Requests for the Applicant:

- *Please clarify the statement on pg. 16 that abandonment will be considered at the wellbore (sidetrack) level. Does this refer to any of the 168 wells to be abandoned on Table 9?*
- *Please clarify the statement on pg. 16 that, "with well abandonment and monitoring, the CO_2 injected will be confined to the Monterey Formation 26R reservoir." Specifically, is monitoring*

(rather than plugging) being considered as an approach to ensure isolation for any wells other than those to be repurposed as monitoring wells?

- *Please clarify the statement on pg. 17 that all wellbores within the AoR will, if necessary, be tested or have a technical demonstration showing adequate zonal confinement prior to the commencement of CO_2 injection. Does this mean that CTV plans to perform additional evaluation of any or all of the 204 wells?*
- *Please add a description of each well's type, construction, date drilled, location, depth, and record of plugging and/or completion to Appendix 1, as required at 40 CFR 146.84 (c)(2).*
- *Please provide the plugging and abandonment (P&A) procedure for the 164 wells described on pg. 17 of the AoR CA to demonstrate that plugging will ensure isolation of the Monterey 26R Formation.*
- *Please clarify the distinction of the 164 wells to be plugged. Specifically, are these wells deficient in any manner; are they the only wells that penetrate the entire thickness of the Reef Ridge Shale; or are they just slated to be plugged as part of field operations?*

AoR Reevaluation Schedule

CTV described the procedures and timing for AoR reevaluations to be performed during the injection and post-injection phases, and the information that will be considered in the reevaluations. At this point in the permit application review, the five-year default reevaluation schedule in the Class VI Rule appears to be appropriate.

Questions/Requests for the Applicant:

- *EPA requests the following revisions to the AoR reevaluation procedures to provide a more robust review:*
    - *Include a review of the full suite of water quality data collected from monitoring wells in addition to CO_2 content/saturation (to evaluate the potential for unanticipated reactions between the injected fluid and the rock formation). Also, review and provide any geologic data acquired since the last modeling effort, including any additional site characterization performed for future injection wells.*
    - *Clarify that the reevaluation modeling results will be compared with the most recent modeling (i.e., from the most recent AoR reevaluation).*
    - *Specify that, if the results of the modeling comparison are consistent, a report describing this determination will be provided.*
    - *Describe the specific actions that will be taken if there are discrepancies between monitoring data and prior modeling results (e.g., remodel the AoR, update all project plans, perform additional corrective action if needed, and submit the results to EPA).*

Triggers for AoR Reevaluations Prior to the Next Scheduled Reevaluation

On page 17, the AoR CA says that an unscheduled reevaluation of the AoR will take place if any of the following scenarios occur:

1) There are changes in operations such as an increase in injection rates, or injection pressure.

2) Differences are observed between the computational model for CO_2 plume development and observed CO_2 plume development, including unexpected changes in fluid content or pressure

outside of the Monterey Formation 26R reservoir that are not related to well integrity, or reservoir pressure that does not behave as predicted with increased injection volumes.

3) Seismic events occur that indicate the presence of faults near/intersecting the confining zone; events that are larger than a 3.5 magnitude and that could be associated with CO_2 injection.

CTV will discuss any such event with the UIC Program Director to determine if an AoR reevaluation is necessary. If an unscheduled reevaluation is triggered, the AoR reevaluation procedures described in the AoR CA plan will be initiated.

Questions/Requests for the Applicant:

- *Please describe the specific injection rate and injection pressure increase CTV referenced that would necessitate an AoR reevaluation, and how such an increase would not involve an exceedance of permit limits.*
- *Please clarify the degree of change in reservoir pressure (e.g., outside three standard deviations from the average) that would necessitate an AoR reevaluation.*
- *Please clarify the timing for conducting an AoR reevaluation (i.e., within 6 months) if any of the triggering events occur.*
- *Please clarify the area over which seismic events greater than M3.5 (e.g., consistent with the Emergency and Remedial Response Plan) would trigger an AoR reevaluation.*
- *Please add the following events to the triggers for an AoR reevaluation:*
  - *Exceeding 90% of the geologic formation fracture pressure in any injection or monitoring wells.*
  - *Detection of changes in shallow groundwater chemistry (e.g., a significant increase in the concentration of any analytical parameter that was not anticipated by the AoR delineation modeling).*
  - *Initiation of competing injection projects within the same injection formation within a 1-mile radius of the injection well (including when additional CTV injection wells come online);*
  - *A significant change in injection operations, as measured by wellhead monitoring;*
  - *Significant land-use changes that would impact site access; and*
  - *Any other activity prompting a model recalibration.*

Post-Injection Site Care Plan

Certain elements of the applicant's Post-Injection Site Care (PISC) and Site Closure Plan (Attachment E) are based on the modeling effort and the results and are evaluated below. See also the Testing and Monitoring report for an evaluation of CTV's post-injection monitoring plan.

As required in 40 CFR 146.93(a)(2)(i) and (ii), the applicant presented the pre- and post-injection pressure differentials and associated maps in the AoR CA. Figure 3 of Attachment E shows the predicted maximum extent of the CO_2 plume and pressure front at 50 years after the end of injection.

Figures 4 and 5 of Attachment E show the monitoring wells and the predicted extent of the CO_2 plume in plan view and cross-sectional view, respectively.

Questions/Requests for the Applicant:

- *Figure 1 in Attachment E shows the reservoir pressure stabilizing at the same time as injection cessation. Please clarify if reservoir pressure will stabilize at this point, or if pressure will stabilize a year after injection cessation as noted in Attachment E, "Pre- and Post-Injection Pressure Differential [40 CFR 146.93(a)(2)(i)]."*

Post-Injection Site Care Time Frame

The applicant proposed a 50-year post injection site care time frame and will not cease post-injection monitoring until a demonstration of non-endangerment of USDWs has been approved by the UIC Program Director pursuant to 40 CFR 146.93(b)(3). The applicant is not proposing an alternative post-injection site care timeframe, so no evaluation relative to the criteria at 40 CFR 146.93(c) is needed.

Non-Endangerment Demonstration Criteria

CTV did not identify the contents of or criteria by which it would support a non-endangerment demonstration at the end of the post-injection site care phase for the 26R project. EPA recommends that CTV propose and include in the PISC and Site Closure Plan a set of criteria that are as specific as possible and can be supported by the data CTV will collect during injection and post-injection testing and monitoring. Incorporating this into the PISC and Site Closure Plan will help reduce future uncertainty and help ensure that CTV will collect the types and amounts of data that are needed to inform a demonstration that authorizing site closure is appropriate. EPA recommends that the non-endangerment demonstration criteria address the evaluation of available groundwater and plume monitoring data; comparison of monitoring data to model predictions; evaluation of the CO_2 plume and reservoir pressure; and an evaluation of any unanticipated events that occurred during the project. See, e.g., Section 3.4 of EPA's "UIC Program Class VI Well Plugging, Post-Injection Site Care, and Site Closure Guidance."

Some specific recommendations to support the preparation of a section of the PISC and Site Closure Plan related to non-endangerment demonstration criteria are provided below:

- *The criteria should specify that the same delineation model that supported the initial AoR delineation will be used in AoR reevaluations and to make the non-endangerment demonstration. This will facilitate verification and/or model calibration using actual monitoring and operational data.*
- *The criteria should discuss the predicted behavior of the CO_2 plume and pressure front, supported by maps and graphs (e.g., of pressure profiles or the extent of the plume and pressure front) in the context of the data that will be collected to demonstrate that the plume and pressure front are behaving as predicted at various points in time.*
- *The data that will support the non-endangerment demonstration should be consistent with the final injection and post-injection phase testing and monitoring strategies in Attachments C and E. They should also be specific as to the types/locations of data that will be gathered and compared against the model prediction to facilitate model validation (e.g., the formations for which groundwater quality data will be collected and pressure monitoring locations).*
- *The criteria should include an evaluation of natural and artificial potential conduits for fluid movement.*
- *The non-endangerment criteria should include evaluations of mobilized fluids and passive seismic data.*

- *The non-endangerment criteria should include a summary of any emergencies or other unanticipated events that may occur during the injection and post-injection phases. This may be presented in a table that shows (1) examples of unanticipated events that might occur, and (2) the types of data that might be used to demonstrate that any associated issues have been resolved such that they will no longer endanger USDWs.*